IMPACT OF SNOW REMOVAL OPERATIONS ON THERMOPLASTIC PAVEMENT MARKINGS

THESIS

Monica L. Monfette, Master Sergeant, USAF

AFIT/GEM/ENV/11-M08

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/GEM/ENV/11-M08

IMPACT OF SNOW REMOVAL OPERATIONS ON THERMOPLASTIC PAVEMENT MARKINGS

THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Monica L. Monfette, MA

Master Sergeant, USAF

March 2011

AFIT/GEM/ENV/11-M08

IMPACT OF SNOW REMOVAL OPERATIONS

ON THERMOPLASTIC PAVEMENT MARKINGS

THESIS

Monica L. Monfette, MA

Master Sergeant, USAF

Approved:

Lieutenant Colonel William E. Sitzabee, Ph.D., P.E (Chairman)	Date
Lieutenant Colonel Peter P. Feng, Ph.D., P.E. (Member)	Date
Alfred E. Thal, Jr., Ph.D. (Member)	Date

Abstract

This pilot study explored the effect snow removal operations have on thermoplastic pavement markings. Including snow removal as a separate independent variable is unique because much of the previous research performed on pavement marking degradation mentioned snow removal as a direct cause in a marking degrading more rapidly; however, it is mentioned as an afterthought and a suggestion to be considered in future research.

This pilot study looked at 10 thermoplastic markings and all marking data were collected in the field, using a hand-held retroreflectometer. Data collection began 60 days after initial marking application and ended 12 months after initial marking application. Data were analyzed using linear regression.

A significant finding was that during the first year, white thermoplastic markings located in the center of the road, and that are exposed to snow removal operations do not reach the apex of their break-in phase. Thus, the start of the linear degradation phase does not start until at least one year after initial application.

I would like to dedicate this to all enlisted AFIT students that arrived after me…if I can finish…so can you. Hope your experience was a good one.

Acknowledgements

I would like to thank my academic advisor, Lieutenant Colonel William Sitzabee, for demonstrating patience when I did not. I would like to thank the AFIT Reference Librarian, Mr. Patrick Colucci, his kindness and assistance was instrumental. I would like to give special thanks to all the AFIT staff members (too many to list) that took a moment (or should I say several moments) to assist me. I want to thank the great folks in the Beavercreek, Ohio maintenance department for allowing me to bombard them with requests and inquiries, specifically, Mr. Mark Biteman and Mr. David Suber.

I owe Captain Dale Mull huge thanks for making data collection so much fun. He is a great Air Force officer and I am glad to have had the opportunity to get to know him…and call him my friend.

Lastly and most importantly, I would like to thank whoever is responsible for the divine intervention that occurred in order for me to survive AFIT. I believe my survival was a direct result of the prayers from Captain Christy Dial (now Licklider) lips to God's ear. Without her support, love, and friendship…much more than this thesis would have been missing. The lessons learned while attending AFIT were not purely academic but much more significant.

MSgt Monica Monfette

Table of Contents

Page

List of Figures

List of Tables

IMPACT OF SNOW REMOVAL OPERATIONS

ON THERMOPLASTIC PAVEMENT MARKINGS

Chapter 1: Introduction

In 1999, the U.S. Department of Transportation (DOT) teamed with the Federal Highway Administration (FHWA) and published *The Asset Management Primer,* which provides a working definition of the evolving concept of asset management:

> *A systematic process of maintaining, upgrading, and operating physical assets cost-effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making. Thus, asset management provides a framework for handling both short- and long-range planning* (U.S. Department of Transportation; Federal Highway Administration, 1999).

America's roadways are significant assets that require management. The modern highway system is a complex component of the transportation infrastructure and its complexity is often overlooked by most vehicle operators. Modern roadways are systems that encompass many parts (subsystems) to make up the system in its entirety, which is often referred to as a large scale system (LSS). It is the LSS that provides vehicle operators a safe reliable means to and from intended destinations (Gibson, Scherer, & Gibson, 2007).

One of the parts, or subsystems, in America's roadways is the pavement surface, which is typically asphalt or concrete. Pavement subsystems represent a large capital investment within the overall roadway system. Maintaining pavement subsystems within the LSS requires careful decisions about resurfacing or other treatments to keep the pavement subsystem in good repair while staying within allocated budgets. An example of such a treatment would be pavement markings, which the Federal Highway Administration (FHWA) defines as the visible lines, symbols, and words actually applied on the surface of the roads (FHWA, 2009). These lines, symbols, and words provide standardized guidance to enhance overall driver safety.

1.1 Background

Debaillon et al. (2009) further define pavement markings by stating that "pavement markings relay a wide variety of information to drivers. They are unique in terms of traffic control devices because drivers do not have to shift their attention away from the roadway in order to receive continuous information." Properly implemented longitudinal pavement markings convey the following information:

- Directional information
- Location of the road center and edges
- Presence of passing or no-passing zones
- Indication that a driver is occupying the correct lane (Debaillon, Carlson, He, Schnell, & Aktan, 2007)

Nighttime drivers are especially dependent on the information relayed by pavement markings. Therefore, the quality of retroreflectivity (R_L), light returned to the

vehicle operator from the vehicle's headlights reflecting off the marking, is an important attribute enabling information to be received by drivers during hours of darkness. The more reflective a marking is, the easier it is for drivers to safely use the markings for the purpose intended.

Various states are making pavement marking asset management an area of concern due to the expense of periodic reapplication of the markings; currently, an estimated $2 billion is spent on annual pavement marking maintenance (Carlson, 2009). States also need guidance in the minimum retroreflectivity required for pavement markings. As of April 2010, the FHWA released guidance on minimum retroreflectivity levels for pavement markings. These minimum levels allow each state to consider its specific roadway attributes and project the service life of the markings. This projection should allow prudent asset management by maximizing the efficiency of restriping programs without sacrificing driver safety, especially nighttime drivers.

Optimizing the pavement marking asset can potentially reduce pavement marking costs (Sitzabee, 2010). Even before FHWA minimum R_L guidelines were released, North Carolina's Department of Transportation (NCDOT) had an interest in pavement markings, specifically in R_L degradation. North Carolina has been proactively collecting data on the state's 78,000 miles of roads; this collection of data is still in progress. Initial pavement marking retroreflectivity readings and their sequential degradation have been recorded for the past eight years. Accurate data will allow NCDOT to best manage its assets and provide a means to quickly identify those roads that do not meet FHWA minimum R_L standards.

North Carolina is supporting additional research in the area of marking degradation, specifically the impact that snow removal operations may have on pavement marking retroreflectivity degradation. North Carolina's desire to ascertain the effects of snow plowing on pavement marking retroreflectivity will optimize the management of this asset. The data collected in North Carolina have resulted in an extensive database, which has been used in several prior publications regarding many areas of pavement marking research.

North Carolina's interest in the degradation of pavement markings caused by snow removal operations sparked the idea for a small-scale pilot study on the effect of snow removal operations on Beaver Valley Road in Beavercreek, Ohio. The pilot study hopes to definitively show the impact snow removal operations may have on the degradation of pavement markings. Future studies could potentially use the Beaver Valley Road findings which could be compared to and, if appropriate, combined with the NCDOT database or other available databases.

This pilot study looked at two types of pavement marking materials that are typically used: waterborne paint and thermoplastics. The two marking materials were separately assigned to an AFIT student; and each student produced an independent thesis. Results from waterborne paint markings can be found in a thesis written by Air Force Captain Dale Mull.

1.2 Scope

Even though both pilot studies will benefit NCDOT as well as other state DOTs in which snow removal operations are performed. This thesis focused on the thermoplastic material used for pavement markings and the impact snow removal operations have on thermoplastic markings. This was accomplished by selecting ten, newly applied, white thermoplastic markings that were located in the center of the driving lane; thereby exposed to maximum traffic as well as maximum snow removal functions. Although the scope of this pilot study was limited to Ohio, many of the lessons can be applied to the United States Air Force in managing their pavement marking assets.

1.3 Objective

The premise of this pilot study is to consider and analyze the specific variables of time, snow removal operations, traffic volume, and initial retroreflective values, then use regression to develop a model to answer the question if snow removal operations have an impact on thermoplastic pavement markings, thereby causing the markings to degrade more rapidly. Finding a definitive answer to this question should narrow the gap in published research and spotlight avenues of future research in this area.

1.4 Organization of the Research

The remainder of this research is organized into four chapters. Chapter Two presents the *Literature Review*; although much literature was reviewed, only eight publications are highlighted in this section. These eight publications directly relate to the importance of this thesis and how this pilot study intends to fill in some of the missing

information regarding snow removal and the degradation of pavement markings. Chapter Three presents the *Methodology* and discusses the method of how data was collected in the field specifically for this project. It is presented in great detail in hopes that the study can either be continued or repeated without difficulties. Chapter Four presents the *Results* and highlights how the observed and documented outcome differed from the anticipated results at the start of the study. Some important "lessons learned" are also presented in Chapter Four; hopefully, this should facilitate any follow-on research by preventing others from reinventing the wheel. Chapter Five presents the *Conclusion* and talks to the future research opportunities that may emanate from this pilot study.

Chapter 2: Literature Review

This literature review chapter is organized into three main sections. The first section provides an overview of retroreflectivity by explaining the general concept and why it is important on our roadways. The second section talks about the current standards for measuring retroreflectivity and how we arrived at the standards that are currently in place. The third and final section summarizes the literature on pavement marking retroreflectivity; this section is broken into subsections to highlight specific publications used in this thesis. The first subsection discusses a study done on the handheld retroreflectometer. The subsequent subsections are organized chronologically, starting with the most recent, and discuss previous studies on retroreflectivity that have some specific element tying them to snow removal.

2.1 Retroreflectivity

To fully understand how pavement markings degrade, an initial understanding of retroreflectivity is helpful. During pavement marking application, glass beads are embedded in thermoplastics while the marking is still in a molten or workable form. These beads create retroreflection of the pavement marking. Retroreflection can be accurately measured by either a mobile or handheld device; the handheld device is pictured later in the Methodology Chapter. The measured retroreflectivity is annotated in millicandelas per square meter per lux ($mcd/m^2/lx$) (Delta, 2004). Figure 1 is a simple visual of how a glass bead is embedded into the pavement marking material and how light rays can strike and then reflect off the glass bead (Hatzi, 2001).

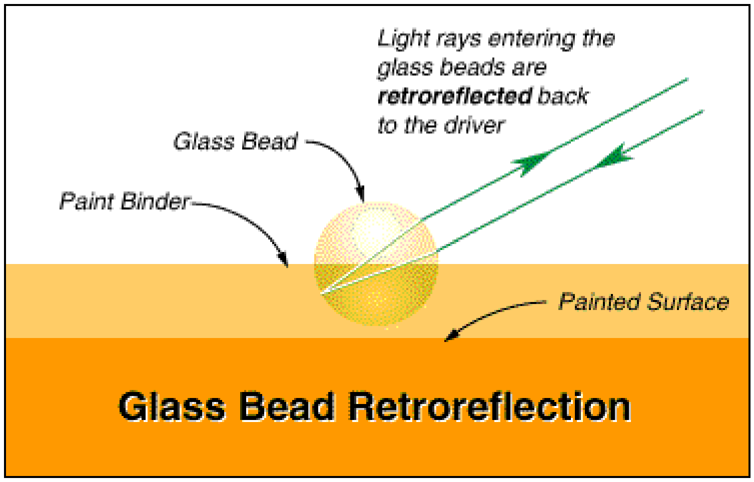


Figure 1. Retroreflection of Light (Hatzi, 2001)

An overarching theme in current pavement marking retroreflectivity literature is the significance of the actual measured value of the marking's retroreflectivity and how that measured retroreflective value directly impacts a vehicle operator's safety during hours of darkness. Experts on the subject have not been able to definitively state the correlation of retroreflectivity and safety; this is because it is believed the presence of reflective pavement markings is just one part of a system which also includes reflective road signs, street lights, traffic signals, guardrails, and raised reflective markers, creating a holistic aspect that connects the nighttime driver with roadway safety (Sitzabee et al., 2009).

2.2 Standards

Moreover, the holistic safety concept regarding nighttime driver safety is so subjective that no version of the Manual on Uniform Traffic Control Devices (MUTCD), often referred to as *The Manual*, to include the most recent 2009 version, specifically addresses minimum levels for pavement marking retroreflectivity standards. The exclusion of such minimum retroreflective standards violated a 1992 congressional ruling which required the Federal Highway Administration to publish, via a MUTCD revision, minimum pavement marking retroreflectivity standards when said markings are "applied to roads open to public travel" (FHWA, 2009; HITEC, 2000).

In search of an industry standard, over the years many states have adopted and implemented policy that any reflectivity value below 100 mcd/m^2/lx marks the end of service life for that specific pavement marking. This 100 mcd/m^2/lx value has also been widely published in mainstream literature as the R_L value marking the end of the pavement marking's service life, regardless of marking material (Sitzabee et al. 2009; Fitch, 2007).

One example is a report published by the state of Vermont in which 30-meter geometry was used to measure the retroreflectivity of pavement markings (Fitch, 2007). Vermont used 100 millicandelas per square meter per lux (mcd/m^2/lx) at the minimum threshold. Although minimum retroreflective standards have not been published, markings measuring below 100 mcd/m^2/lx were categorized as needing replacement.

In April 2010, a long overdue proposal for a revision to the 2009 MUTCD was submitted to the *Federal Register*. This proposal included minimum standards for pavement marking retroreflectivity. As of January 2011, the Federal Highway Administration is still reviewing comments the proposal generated; however, in the meantime, the FHWA website has provided links in which the proposed text that defines the retroreflectivity requirements can be viewed (FHWA, 2009)

Table 1 shows the proposed minimum retroreflectivity. These minimums represent the pavement marking solely and do not consider the significance of any additional factors previously mentioned, such as the presence of guardrails or street lights. Compliance with the minimum levels is reportedly going to cost $64 million annually on top of the $2 billion already spent on marking maintenance (Carlson, 2009; Hawkins, Lupes, Schertz, Satterfield, & Carlson, 2010).

Table 1. Minimum Retroreflective Levels for Longitudinal Pavement Markings

	Posted Speed in MPH		
	≤ 30	35 – 50	≥ 55
two-lane roads with centerline markings only		100	250
all other roads		50	100

*adopted from FHWA website and measured in mcd/m^2/lux using 30-meter geometry

ASTM E1710, *Standard Test Method for Measurement of Retroreflective Pavement Markings*, states that portable retroreflectometers, such as the ones used in this

pilot study, need to adhere to the 30-meter geometry standard (ASTM, 2009). The 30-meter geometry is a FHWA standard and provides agencies with a common guideline for collecting and recording R_L measurements. Figure 2 pictorially defines the standardized 30-meter geometry originally created by the European Committee for Normalization (CEN) and later adopted by the American Society for Testing and Materials (ASTM) (ASTM, 2009). It shows how the average driver looks out the windshield approximately 30-meters in front of the automobile; therefore, that is where the value of the refraction of light is measured. It is important to note that previous to the 30-meter geometry standard, 12- and 15-meter geometry was a common measurement; however, since the 30-meter geometry was adopted by the United States, 12 and 15-meter intrustruments are no longer used to measure pavement markings (HITEC, 2000). Some literature prior to the 30-meter geometry adoptions used 12- or 15-meter measurements. Although the math cannot match up with more recent studys, the overall processes, observations, and lessons learned may still be very revelent and therefore are included in the literature reviewed for this pilot study.

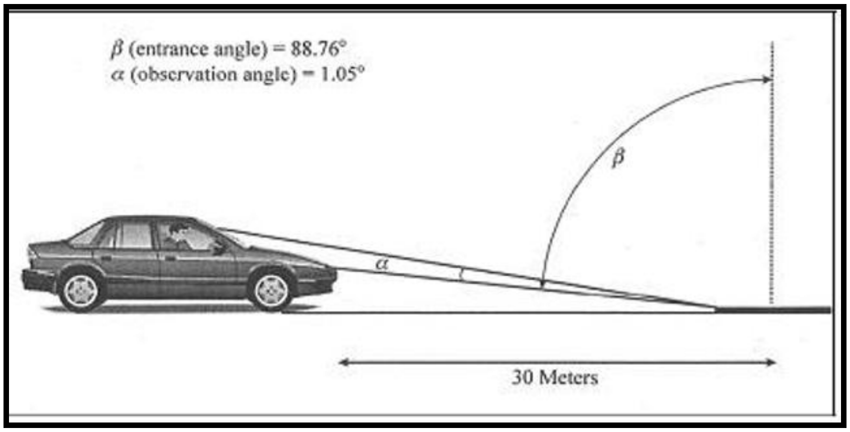


Figure 2. 30-Meter Geometry (HITEC, 2000)

2.3 Literature Used to Shape Thesis

Table 2 summarizes the literature that guided the overall direction of this thesis. Immediately after the table, a brief summary of handheld retroreflectometers is given. That summary is followed by a short overview of each study presented in Table 2 and how each study provided support to help negotiate the path of the Beaver Valley Road research.

Table 2. Literature Used to Shape Thesis and Significant Findings

Year	Author	Title and Purpose of Study	Key Findings
2000	Highway Innovative Technology Evaluation Center	*Evaluation Findings of the LTL 2000 Pavement Marking Retroreflectometer*	• Predecessor to the LTL-X • Can't be compared to 12- or 15- meter retroreflectometers
2007	US Department of Transportation	*Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs* R_L to meet nighttime driver's needs	• 130 mcd/m^2/lx
2007	Craig, Sitzabee, Rasdorf, Hummer	*Statistical Validation of the Effect of Lateral Line Location on Pavement Marking Retroreflectivity Degradation*	• PM location on roadway matters - arrows will be subjected to max traffic and plowing
2007	Vermont Fitch	*Pavement Marking Durability Statewide Final Report*	• Data collected with LTL 2000 • Tried to clean pavement of debris • Winter maintenance had great effect on R_L degradation • Markings showed springtime rebound

2003	South Carolina DOT Sarasua, Clarke, Davis	*Evaluation of Interstate Pavement Marking Retroreflectivity* Clemson performed study for SCDOT	• Thermoplastics PM showed significant R_L increase after application • Degrades 10-70 mcd/m^2/lx per year • Snow plowing influence degradation • Validated LTL 2000 performance (ambient light, climate, road conditions)
2001	TRB Synthesis	*NCHRP Synthesis 306 Long-Term Pavement Marking Practices*	• Severity of winter does not contribute service life of marking BUT snow operations do • Linear regression used
1999	Michigan Lee, Maleck, Taylor	*Pavement Marking Material Evaluation Study in Michigan*	• AADT and speed limit of roadway do not contribute to R_L decrease • Snow plowing and deicing do contribute • Linear regression used
1994	Bagot, Keith	*Evaluation of Retro-Reflective Beads in Airport Pavement Markings*	• Larger beads more snow plow damage • Larger beads brighter initially, smaller beads outperformed after 1 year • Airport with no snow still showed R_L decrease but not as fast

2.3.1 Handheld Retroreflectometer

Figure 6, in section 3.3, shows a picture of the LTL-X model on a test location. The LTL-X is the fourth generation of handheld retroreflectometers manufactured by Flint Trading; the LTL-2000 is a predecessor of the LTL-X model.

Handheld retroreflectometers must meet three criteria (HITEC, 2000):

1. *measurement bias* – measure test panels at several photometric ranges, the average of the range was used as a baseline to compare readings taken with the handheld unit
2. *repeatability* – handheld unit's ability to obtain identical readings at the exact same point (in the Beavercreek, Ohio pilot study three consecutive readings were taken at each location and the average was used; the readings were typically within one point, refer to Appendix A for actual data collected).
3. *reproducibility* – use of different units to produce the same readings at same location (this was done when the switch from LTL-2000 to LTL-X was made)

Handheld units must also be calibrated; this is done in the field by setting the unit to zero then performing the calibration to meet the standard established standard (HITEC, 2000). It is important to note, pavement markings with different shapes or size, day or nighttime data collection, or different pavement surfaces, do not affect the performance of the unit and no alterations are needed in the way the unit is used.

Some findings of the laboratory tests performed on the LTL-2000 found that condensation on the marking could impact the readings (HITEC, 2000). In the field test, it was noted that the reading was consistent between different units on the same location but moving the unit just slightly to a different location could produce a much lower or

higher reading, thereby implying that variations exist regarding the actual uniformity of the marking. The exact reason for this is unknown.

2.3.2 Department of Transportation 2007

This publication looked at several studies that surveyed drivers and matched their comfort levels with actual pavement marking retroreflectivity. One approach of the Minnesota Department of Transportation (MnDOT) study was that vehicle operators were exposed to pavement markings with differing R_L values and individually asked to rate the quality of the markings based on their personal comfort levels. MnDOT found that as the pavement marking retroreflective values increased, so did driver comfort levels.

An intensive human factors study addressed the interaction of the “human system” with the pavement marking system. Specifically, values from 0 – 120 mcd/m^2/lx received the most dramatic increase in driver acceptance. Values from 120 – 200 mcd/m^2/lx showed a shallower incline of driver acceptance as the R_L values increased. Markings with known R_L values of 200 mcd/m^2/lx or more received virtually no comments regarding increased comfort levels from individual drivers.

Interestingly, MnDOT’s recommendation for roads with centerlines and edge lines, and a speed limit less than 50 miles per hour, was 40 mcd/m^2/lx. Referring back to Table 1, it is seen that this recommendation is close to the proposed MUTCD value for a road with the same characteristics of having both a centerline and edge lines. Historically, 100 mcd/m^2/lx has been industry’s accepted threshold to mark the end of life

for any pavement marking, regardless of additional pavement markings or speed limit. It is important to note that the road used in this pilot study, Beaver Valley Road, has a speed limit of 35 mph, and it has a centerline and edge lines; therefore, it is prudent to implement 50 $mcd/m^2/lx$ as the least retroreflectance before marking replacement should be considered.

2.3.3 Craig, Sitzabee, Rasdorf, and Hummer 2007

This article examined the lateral location of the pavement markings to ascertain if marking location was significant in marking degradation. Over a five year time frame, edge lines and centerlines were studied and the result was that centerlines degrade faster than edge lines. This finding helped shape the Beaver Valley Road study because the thermoplastic pavement markings studied on Beaver Valley Road are directional symbols and are located in the middle of driving lanes; therefore, it can be inferred that these markings are located such that they receive maximum exposure to traffic and snow plow operations. To help visualize the actual marking locations of Beaver Valley Road, refer Figure 6 and Figure 7 located in section 3.3.

2.3.4 Vermont 2007, Fitch

The Vermont study looked at 25 areas of various pavement marking materials between 2002 and 2005. Some of the markings were recessed and others were applied to the pavement surface. Surface application is how the Beaver Valley Road markings were applied.

Vermont utilized a handheld retroreflectometer, which is what the Beavercreek, Ohio, pilot study also used. Like the pilot study, they also took readings in weather below the manufacturer's recommended temperatures and they also attempted to clean the marking of debris before taking a reading with the retroreflectometer. The study revealed that surface markings degraded faster than recessed markings; this observation supports the assumption that markings exposed to winter snow plow operations degrade more rapidly. What the Vermont study suggested is that one winter season with snow plow operations accounted for more than 100 mcd/m2/lx of R_L degradation; although it was not mentioned if that season was the first, second, or seventh, winter season. The markings on Beaver Valley Road did not have similar results; however, it was Beaver Valley's first winter season and it is unclear how many more winter seasons the Vermont markings were exposed prior to such a significant decrease.

2.3.5 South Carolina DOT 2003, Sarasua, et al.

This report served as validation regarding the data collection method chosen in the Beaver Valley Road pilot study. Researchers from South Carolina and Clemson University compared different retroreflectometer devices. Comparisons were made between mobile and handheld retroreflectometers, as well as different models of handheld retroreflectometers. The result showed that handheld devices out-performed mobile devices; and specifically, that the LTL 2000 model performed exceptionally well regarding ambient temperatures that fell outside the manufacturer's recommended range. The LTL 2000 model is what was initially used in the Beavercreek, Ohio, pilot study.

Another finding from South Carolina, repeated in other literature (Craig et al. 2007; Sarasua et al. 2003; Taek et al. 1999; Bagot, 1994) is that snow plowing operations increased the degradation of pavement markings. Northern tier states involved in this study specifically stated that, in their opinion, winter maintenance strongly influences the pavement marking service life. Unfortunately, in this research South Carolina did not devise a model to capture the rate of degradation of said markings.

Lastly, it is important to note that the South Carolina study found that thermoplastic pavement markings showed a significant increase of retroreflectivity values after initial application of the markings. The importance of this finding becomes more significant because the Beaver Valley Road data show an increase in the R_L value for all the markings. Figure 12. RL Increase after Initial Application shows how the R_L values of thermoplastic pavement markings will show a significant, non linear increase, after initial application (Sarasua et al. 2003). Once a summit is reached, the natural degradation will begin. Plenty of models have captured the degradation; none to date have pinpointed the time in which the apex is reached. What is assumed is that the apex may be reached sooner in markings that are exposed to snow removal operations. This is yet to be validated.

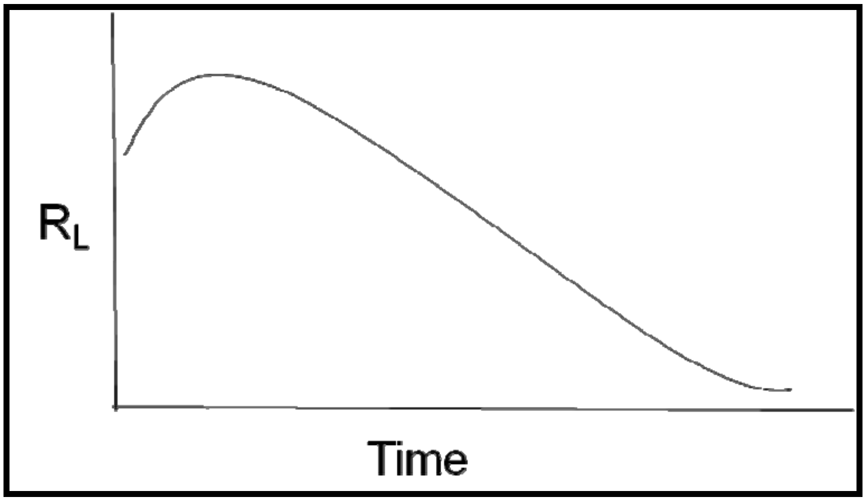


Figure 3. Predictive Curve for Newly Applied Pavement Markings

2.3.6 TRB Synthesis (Migletz & Graham, 2001)

This study was a synthesis that summarized all the literature from 1988 through 2001. Many aspects of pavement markings were presented through a study of 85 sites in 19 different states. The focus was on linear regression models to determine the degradation of pavement markings. This study evaluated many road types and marking types to include white thermoplastic markings placed on asphalt in regions that perform snow removal operations, which mirror the Beaver Valley Road attributes.

While it was noted that the severity of the snow and climate did not contribute to the degradation of the marking's retroreflectivity, it was made clear that the actual snow removal operations did cause the marking to degrade more rapidly. The authors stated, "…snow removal is a major concern in many areas and pavement markings can be damaged during snow removal operations. Being able to maintain markings in snow

removal areas presents a major challenge…" (Migletz & Graham, 2001).   It is also important to note that in this study the initial retroreflectivity reading were conducted within the first sixty days after application; this means that the Beaver Valley Road readings were collected at a point in time that is consistent with other studies.

2.3.7 Michigan 1999

This study, conducted over a four year period, evaluated various pavement marking materials used for lane delineation. The study included 50 sites in various regions with different climates. One of the variables considered was annual average daily traffic (AADT), and it was found to have no significance on R_L degradation; however, it was observed that regions with increased snow removal operations showed higher degradation rates compared to areas with less snow removal activity. The authors suggested that snow removal be considered as a variable in future research. The Michigan study agrees with other studies in finding AADT to be insignificant. As a result, during design of the model used for the Beaver Valley study, AADT was never considered as a separate variable; however, snow removal was entered as a separate variable.

2.3.8 Bagot 1994

This one-year study looked at different sized beads imbedded in airfield markings and how those beads held up when exposed to snow removal operations. Even though this study was conducted more than 15 years ago and was originally meant to compare airfield markings of three separate airfields, it fits the Beaver Valley pilot study in that not all of the airfields required snow removal operations due to differing climates. Interestingly, the researchers noted that as the number of snow plow strikes increased the degradation of the airfield markings also increased. The authors stressed that larger beads were more susceptible to snow removal operations; however, the smaller beads on airfields with snow removal operations also showed a more rapid degradation compared to airfields without snow, and therefore, without snow removal operations.

2.4 Summary of Literature Review

The literature summarized some studies that have been previously conducted. The first publication discussed the handheld retroreflectometer and gave this measuring device credibility; this is important since a handheld retroreflectometer was used in the Ohio pilot study. The remaining literature review introduced seven different studies related to pavement marking degradation, a few of which used linear regression modeling to capture the degradation rates of pavement markings. Each study was selected in this literature review to show that many researchers believe snow removal has an impact on pavement marking degradation; however, none specifically included it in their research and therefore it was not included in their models. The Ohio pilot study does consider

snow removal operations as a separate variable and the next chapter will fully define all variables as well as the methodology used.

Chapter 3: Methodology

This section presents the methodology used for this pilot study, beginning with the test location and how safety played a part in this location being selected. The handheld retroreflectometers are picture here and discussion on how exactly data was collected with this devices is discussed. Lastly the plan to analyze the data is introduced.

3.1 Test Location

In this study, an appropriate test deck of pavement markings was required and assistance was sought from the Public Service Division located in Beavercreek, Ohio. Of the 560 lane miles and 317 cul-de-sacs for which this division is responsible, several roadways were identified as having newly applied pavement markings (Biteman, 2009). After some consideration, a 1,955 foot segment on Beaver Valley Road was selected, Figure 4 .

Figure 4. Map of Beaver Valley Road

3.2 Safety

Safety is a concern because using a handheld retroreflectometer device puts data collection personnel in the middle of the roadway. Therefore, much consideration was given when the test location were selected. This pilot study's road segment was ultimately chosen for safety aspects, one of which was how much traffic would the data collection personnel be exposed to. Beaver Valley Road has an Annual Average Daily Traffic (AADT) of 4,000 vehicles per day, making this a relatively low volume roadway.

According to an online route finder that also depicts route elevation, the Beaver Valley segment features 82 feet of elevation variation (Create a Route, 2010). This nearly flat section of roadway provides the vehicle operators a clearer line of sight of data

collection personnel who would be located on the roadway. The low AADT and limited elevation change met initial safety concerns; however, the 1,955 feet of road segment selected was deemed even safer because of a designated turn land that ran the entire 1,955 feet. This provided vehicle operators ample room to drive around data collection activities without jeopardizing the safety of the vehicle operator or the data collection personnel.

Additional measures taken to ensure safe data collection included an orange diamond shaped “workers ahead” sign; fluorescent safety vests worn by data collection personnel; use of blinking, vehicle equipped, hazards lights; and a flashing beacon atop the truck used to transport data collection personnel. Figure 5 shows the safety equipment used and the approved safety plan can be seen in Appendix D; this safety plan follows Ohio’s Department of Transportation standards and was approved an unit safety representative assigned at AFIT.

Figure 5. Safety Devices Used

3.3 Exact Locations and Marking Material

There were 10 thermoplastic data collection points on Beaver Valley Road. All thermoplastic markings were symbols, *turn arrows* and *only*, applied on 8 October 2009 (Biteman, 2009). When data collection began on 12 December 2009, the thermoplastic markings had never been plowed. Table 3 shows the GPS coordinates of the 10 marking locations, Figure 6 shows the handheld retroreflectometer on its measurement location on a turn arrow, and Figure 7 shows the word ONLY; the red line, made known by black arrow, depicts where the base of the retroreflectometer was placed. The five turn arrow and five "L" thermoplastic data collection points were selected on the basis of availability safe location within the 1,955 foot road segment.

Table 3. GPS Coordinates for 10 Thermoplastic Test Locations

Test Location	GPS North	GPS West
1 = "L"	39 °43.770	- 084 °01.176
2 = "turn arrow"	39 °43.777	- 084 °01.175
3 = "L"	39 °43.750	- 084 °01.179
4 = "turn arrow"	39 °43.743	- 084 °01.178
5 = "L"	39 °43.560	- 084 °01.238
6 = "turn arrow"	39 °43.555	- 084 °01.238
7 = "L"	39 °43.561	- 084 °01.238
8 = "turn arrow"	39 °43.556	- 084 °01.240
9 = "L"	39 °43.313	- 084 °01.319
10 = "turn arrow"	39 °43.306	- 084 °01.324

.

Figure 6. LTL-X Retroreflectometer on Arrow Location

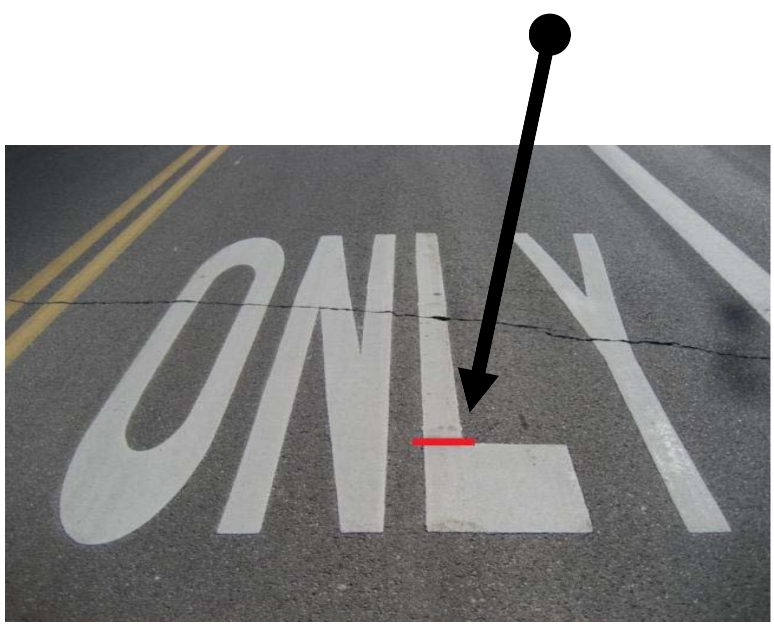


Figure 7. Placement of Retroreflectometer on L Location

3.4 Devices to Collect Data

A handheld retroreflectometer that met the American Society for Testing and Materials (ASTM) 30-meter standard was used for all data collection (ASTM, 2009). Figure 2 in section 2.2, provides a visual depiction of the 30-meter standard.

The retroreflectometer was stored in an unheated garage and transported in the bed of a pick-up truck with a hard bed cover; therefore, the device was exposed ambient temperatures that reflected the test location. A field calibration was performed immediately prior to data collection.

Initially, the LTL 2000 was used as a loaner; however, midway into the process a new retroreflectometer, the LTL-X, was purchased. The LTL-X, seen in Figure 6, was first used on 5 March 2010 and was used for the remainder of the data collection process. Thermoplastic data collection concluded in October 2010. When the LTL-X was introduced, readings with both units were conducted to ensure equivalence in the RL value recorded by the two units but only the LTL-X readings were annotated on data collection sheets.

Several factors determined the choice of a handheld device. Cost was a factor, but practicality and safety were the primary factors. Since there were only a total of 88 test points (ten were the thermoplastic points addressed in this thesis and 78 were the waterborne points addressed in Captain Dale Mull's thesis), utilizing a handheld data collection device was more feasible.

3.5 Data Collection Sequence

The initial readings were conducted on 12 December 2009. Three separate readings were collected at each test spot and an average reading for that spot on that specific day was calculated. The actual data collected on the 10 thermoplastic locations are shown in Table 4 and Appendix A.

The maintenance department of Beavercreek, Ohio, has a snow strategy memorandum, Appendix B, and it states that actual plowing does not take place until snow has accumulated in excess of three inches; any accumulation less than three inches receives salt/limestone grit. This is important because even though data collection began after the markings were exposed to salt/limestone grit and brine solution; all data collection began before these ten thermoplastic marking locations were ever exposed to a snow plow.

The first snow removal operation that dispatched actual plow trucks to remove the snow began on 28 December 2009. Between initial readings and the first snow event there had been some surface preparation for freezing weather; sand/limestone grit mixture as well as a liquid brine solution had been applied in accordance with the snow strategy policy. These applications were separately documented but for the purpose of the study on the 10 thermoplastic marking test spots, these pretreatments are captured as "snow removal operations", Figure 8 shows the plow truck and shows the blade on the truck. Ohio's snow strategy is to plow to pavement, which means the blade actually comes in contact with the road surface and subsequently the pavement markings. Figure

9. Salt/Limestone Grit in Bed of Plow Truckdepicts the salt/limestone grit that is applied to the roadway; each salt/limestone grit application was captured in the snow removal operations.

Figure 8. Plow Truck Used on Test Deck

Figure 9. Salt/Limestone Grit in Bed of Plow Truck

During the plowing season, data collection of the retroreflectivity was scheduled on an approximate weekly basis; after the snow season, R_L collection occurred monthly. Variations in time between the snow season data collection events were due to weather and personal schedules. For example, during the month of February, several snow storms occurred, making data collection impractical. The snow covered roads made it unsafe for data collection personnel to be in the roadway and the pavement markings were not accessible because they were covered with snow and ice. It is important to note that while retroreflective measurements were not being collected, snow removal data were still being collected.   Table 5 in section 4.3, shows the comparison of the initial readings taken on 12 December 2009 and the final thermoplastic pavement marking readings taken on 12 October 2010.

3.6 Analyzing the Data

The method by which the Ohio pilot study will analyze the data from the 10 thermoplastic spots will be with JMP® statistical software. A mixed stepwise regression was used to validate the variables; this is explained in section 3.6.1 and then those variables were inserted into a model, which is discussed in section 3.6.2.

3.6.1 Mixed Stepwise Regression

First a mixed stepwise regression will be used to validate the variables; the JMP® stepwise feature computes the estimates and selects variables that should remain in the model based on a 95 percent significance level. The mixed stepwise was used to ensure that each time one variable was selected or eliminated the computer software went through the remaining variables again to reconsider them for selection or elimination.

3.6.2 Linear Regression

Linear regression takes a set of inputs to predict a single output. This statistical modeling is a common method to model the degradation of pavement markings because marking degradation has a natural linear decline. Therefore, that was the method chosen for the Ohio pilot study. Since linear regression assumes three things: 1) variables are independent and normally distributed; 2) the population variances are equal; and 3) the regression is basically depicted by a straight line (Rao, 1998); JMP® was again used to validate these three assumptions by inserting the data and producing a residual by predicted plot, a histogram of the residuals, a Q-Q Plot, and a Shapiro-Wilk Test. The residual plot can help visually determine if the variances are equal about the mean and

the Q-Q plot is also a visual tool to see if the residuals form somewhat of a straight line. If both these visual tools check out, then the assumptions are validated.

Chapter 4: Results

The results of this study did not follow the plan laid out by the researchers in the beginning of the study. For example, the whole concept was to include snow removal operations as an independent variable; however, it fell out of the model when fitted by the stepwise selection function in JMP®. Even though some things fell out, some other items from previous publications were validated; such as the R_L value increasing after initial application. This section will define the variables and explain why they were or were not included in the linear regression model. The equation used will be introduced here as well. Finally, the results will be discussed and compared in some areas to studies introduced in Chapter 2, *Literature Review*. This is followed by model validation and some lessons learned.

4.1 Variables Considered and Defined

All data collected were analyzed using JMP® commercial software. The following eight variables were initially considered for inclusion in the model:

- AADT (annual average daily traffic)
- Lateral Line Location
- Pavement Marking Material
- Snow plow only operations (only the plow)
- Snow plow operations to include salt/limestone grit and brine applications and the plow

- Age (in days)
- Initial R_L (readings collected on 12 December 2009 were used as initial R_L)
- Current (or final) R_L collected on 12 October 2010

4.1.1 Excluded Variables

Some variables did not make it into the final model either because they failed to meet the 95 percent significance level set up in the mixed stepwise selection done through JMP® or for other logical reasons; the reason for exclusion is made clear below.

4.1.1.1 Average Daily Traffic (ADT)

Only one road was studied and therefore traffic volume was the same for all markings. It is important to note that the Beavercreek maintenance department performed a traffic count beginning on 21 September 2010 at 0000 hours and ending 24-hours later on 22 September 2010 at 0000 hours. During this 24-hour period, the raw count for the south bound lane was 3,945 and the raw count for the north bound lane was 3,748. This is consistent with the last previously recorded reading performed on 1 May 2008, where the south bound and north bound lane raw counts were 4,110 and 3,805, respectively. These numbers categorize this stretch of road as having low AADT, fewer than 4000 vehicles day, by industry standards.

4.1.1.2 Lateral Line Location

All markings were located in the center of the lanes; therefore, they were assumed to receive equal exposure to all salt/limestone grit applications as well as snow plow activity. The Beavercreek Snow Strategy, seen in Appendix B, states, “only after the entire street system has been treated and plowed for traffic shall crews return to plow the balance of the street to the curb if so needed” (Brown, 2009). Thus, a logical assumption is that the markings located in the center of the roadway receive maximum snow plow exposure.

4.1.1.3 Pavement Marking Material

All pavement markings in the study were of the same material so this variable was not included in the model. For informational purposes, the markings were white thermoplastic PreMark™ and were 125 mil thick. This material is listed in the Ohio Department of Transportation’s authorized materials list (Davis, n.d.). Ohio’s target R_L value at application is 400 mcd/m^2/lx, and PreMark meets this target (Davis, n.d.). Premark specifications at initial application are a retroreflective value of 500 mcd/m^2/lx (Flint Trading Inc., n.d.).

4.1.1.4 Snow Plow Only Operations

Using JMP® statistical software, a mixed stepwise analysis, discussed in section 3.6.1, was use to validate variables and “snow plow only” operations did not meet the 95 percent significance level and therefore this variable fell out of the final model.

4.1.1.5 Snow Plow Operations to include salt/limestone grit and brine applications

This variable also fell out of the final model when a mixed stepwise analysis, discussed in section 3.6.1, was performed. The “snow plow operations to include salt/limestone grit and brine applications” did not meet the 95 percent significance level.

4.1.2 Variables Used and Resulting Equations

Only three variables passed the 95 percent significance in the mixed stepwise fit seen in Figure 10. The three variables that were included in the final model are:

1) Current/Final R_L
2) Age (in days)
3) Initial R_L

Stepwise Fit

ResponseCurrent RL

Stepwise Regression Control

Prob to Enter 0.050
Prob to Leave 0.050
Direction: Mixed

Current Estimates

SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AICc
586277.17	117	5010.916	0.6461	0.6401	3	1368.18

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Intercept	30.7434718	1	0	0.000	1
		Age (days)	0.74086507	1	720407.7	143.768	4.3e-22
		RLI	0.74800043	1	350044.7	69.856	1.5e-13

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	Age (days)	Entered	0.0000	720407.7	0.4348	70.856	2
2	RLI	Entered	0.0000	350044.7	0.6461	3	3

Figure 10. Mixed Stepwise Variables Selected

These variables produced the following regression model of

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \tag{1}$$

Where

Y = *dependent variable*, Current R_L

X_1 = *independent variable*, Age in Days

with day zero on 12 Dec 2009

X_2 = *Initial* R_L

β = *coefficients*

ε = *random error*

Using this model, the predicted equation for the 305 days (12 Dec 2009 – 12 Oct 2010 was

$$R_L = 31 + .74{*}age\ in\ days + .75{*}R_L\ initials \tag{2}$$

4.2 Expected Results

The anticipated results of this pilot study were for the retroreflectivity of the thermoplastic pavement marking to decrease as snow removal operations increased; and it was expected to be able to predict the amount of decrease in order to assist with marking replacement timelines.

4.3 Initial Results Unexpected

The model had the current R_L as the Y variable (dependent variable) and age in days and initial R_L as the model effects (independent variables). The actual by predicted plot, Figure 11, shows how the retroreflectivity increased with no visual clues that it would stop; this makes no sense for a marking to continually become more reflective as time passes.

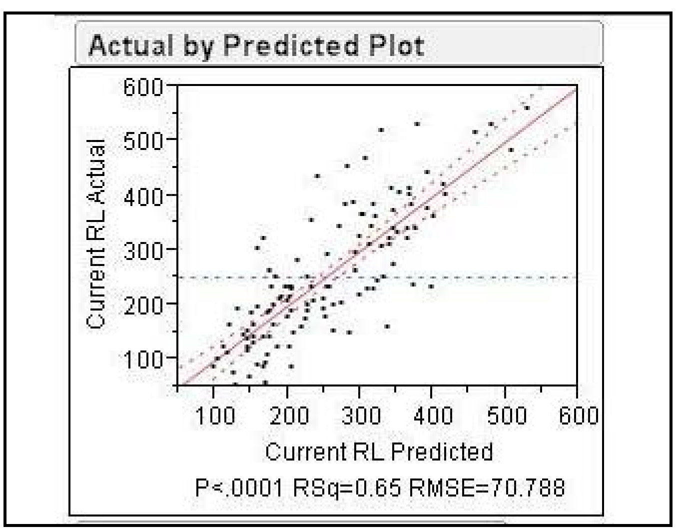


Figure 11. Actual by Predicted

The seemingly never-ending R_L increase means that there must be other factors contributing to this result. Some initial speculations were:

The first reading (also the initial reading) was recorded on 12 Dec 2009, only two months after the pavement marking was applied. This initial reading seen in Table 5 was extremely low for such a newly applied marking. The climate in Ohio in December is cold and Beaver Valley Road had already received four treatments to reduce ice on the roads. Similar to the 2007 Vermont study, all the Ohio data collected during the winter months revealed erratic variations in the R_L values (Fitch, 2007); the assumption for Beaver Valley Road was the brine solution that is applied leaves a film on the road surface which limits the ability of the handheld retroreflectometer to obtain accurate readings.

In the Vermont study, data collection personnel attempted to cleanse the data collection points with a pressure washer before collecting readings. This approach did not produce consistent readings and they, Vermont, abandoned cleansing the collection points (Fitch, 2007). On two separate occasions in the Beaver Valley Road pilot study, a broom was used to sweep away any salt or sand on the data collection point. However, sweeping did not cause readings to improve; sweeping the collection point actually caused the readings to decrease by more than fifty percent. Therefore, collection personnel decided to cease sweeping.

This decision was based on three factors. One was that Vermont also found no benefit to cleansing the area. Second, the Beaver Valley Road showed considerable decreases in the R_L measurements after being swept clean of salt and sand residue. Third,

in authentic driving conditions the markings would not be cleaned for vehicle operators. The team decided to capture and record the true measurement of the marking retroreflectivity as viewed by drivers.

The readings began to level out once spring arrived and the brine and salt residue was washed from the roads by the rain. The readings for each collection day are shown in Table 4 and a comparison of initial and final R_L values are shown in Table 5.

Table 4. RL Values Collected

all spots are average of 3 readings taken that day										
Date	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
12-Dec-09	113	143	191	144	365	214	162	186	88	151
18-Dec-09	165	122	201	139	228	235	304	263	102	186
30-Dec-09	193	129	210	143	228	190	321	251	122	195
18-Jan-10	115	86	122	142	252	161	164	180	77	109
23-Jan-10	69	59	88	93	160	176	251	215	54	141
5-Jan-10	232	209	208	232	413	293	280	355	91	229
9-Apr-10	235	190	152	202	435	233	444	385	124	232
10-May-10	251	193	150	210	202	452	422	365	148	233
7-Jul-10	345	264	307	296	514	373	469	244	177	326
5-Aug-10	386	309	331	345	531	401	518	272	204	360
10-Sep-10	385	309	341	320	484	375	405	238	217	339
12-Oct-10	414	323	361	341	558	402	530	232	244	385

Table 5. Initial and Final Data Compared

Location	Initial R_L 12 Dec 2009	Current R_L 12 Oct 2010	Age (in days)	Snow Ops (plow only)	Snow Ops (sand/salt brine and plow)	Delta	Mean	SD
1	113	414	305	42	106	+301	242	118
2	143	323	305	42	106	+180	195	91
3	191	361	305	42	106	+170	222	92
4	144	341	305	42	106	+197	217	89
5	365	558	305	42	106	+193	383	135
6	214	402	305	42	106	+188	298	96
7	162	530	305	42	106	+368	337	132
8	186	232	305	42	106	+46	260	75
9	88	244	305	42	106	+156	137	61
10	151	385	305	42	106	+234	241	92
Mean	176	379						
SD	76	106						

Realizing that an indefinite increase in R_L is not possible, it is safe to assume that another reason for the increase in retroreflectivity may be because the thermoplastic marking was applied in October 2009 and is still in the break-in phase of the marking. This break-in phase has been considered and documented in previous research (Sarasua, et al.); during this phase, it is common for a marking's retroreflectivity to increase before

it starts its natural decrease. This is captured in the South Carolina study mentioned in the literature review; Figure 3 in section 2.3.5 offers a visual depiction of this occurrence. The increase is due to the top layer of thermoplastic binding wearing away and exposing beads that were more deeply embedded upon initial application. Thermoplastic is long-life (durable) pavement marking, so as the top layer of binding material is worn away more bead surface is exposed increasing the overall retroreflectivity of the marking.

Based on this information, it is safe to assume the markings on Beaver Valley Road were still in the break-in phase when the last reading was collected on 12 October 2010. The break-in phase is definitely an area for further discussion and research to ascertain if snow removal operations significantly contribute to thermoplastic marking degradation during the break-in phase of the marking even when R_L values seem to be increasing.

Another good reference is the 1994 Bagot study, also mentioned in the literature review section. This study compared airport markings in different regions, some markings were exposed to snow removal operations and some were not. It was found that markings of the same material and bead size did increase in R_L value, but those exposed to snow removal operations had a value less then markings not exposed to snow removal operations (Bagot, 1994). Figure 12 is a depiction this concept, this figure was created by the author of this thesis. It is a combination of the Sarasua graph in section 2.3.5 and fresh input to depict the region without snow removal.

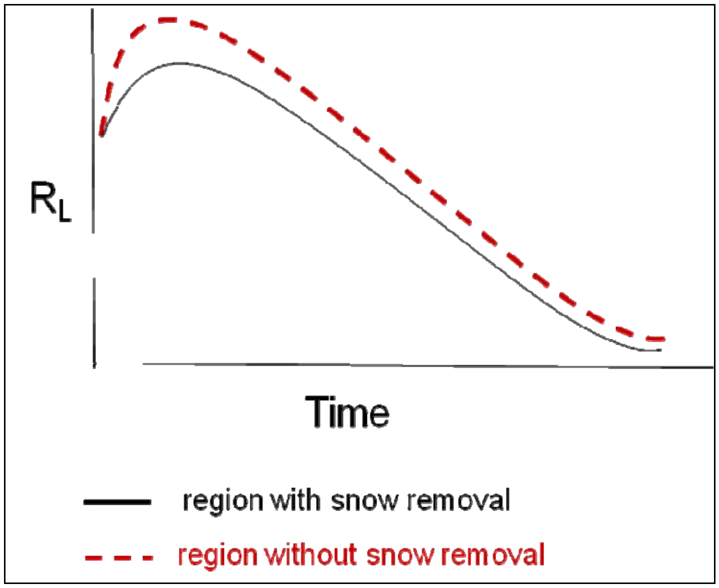


Figure 12. RL Increase after Initial Application

Satisfied that the reason for the R_L increase is due to the marking not reaching the crest of the break-in phase and begin a natural decline, the data were analyzed further.

4.4 Model Validation

Section 3.6.2 states that linear regression requires that three assumptions be met: 1) responses are independent and normally distributed; 2) population variance is equal; and 3) the regression represents a straight-line function.

A review of the statistical software output will show that the model used is valid because it meets constant variance and normality measurements as seen in Figure 13, Figure 14, and Figure 15. Figure 13 shows an even distribution of the residuals about the

mean. There is no increase or decrease in the variances and this is true because the output is not fanned or coned shape (Rao, 1998).

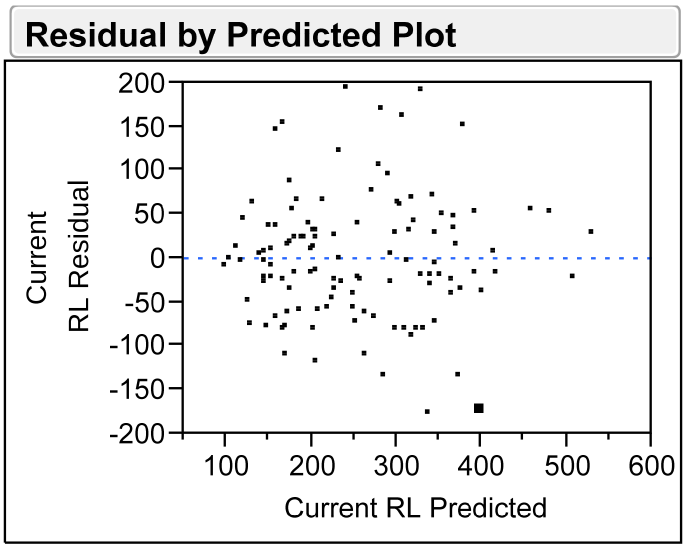


Figure 13. Constant Variance of Residuals

The bell curve in Figure 14 also visually validates that the data come from a normal distribution.

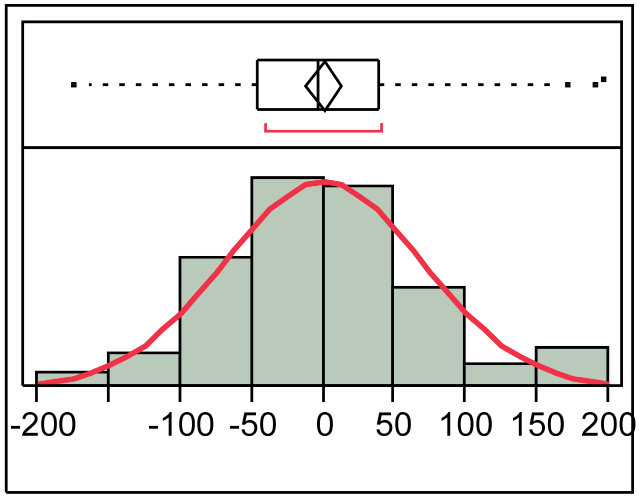
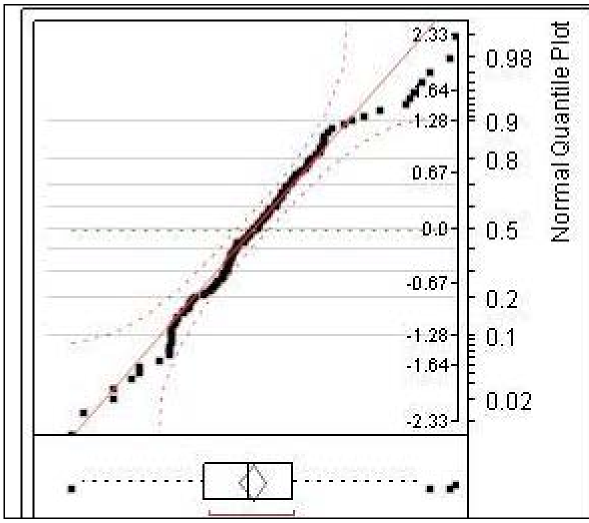


Figure 14. Distribution of Residuals

Validation of normality with the Q-Q plot consists of graphing the residuals against a standard for a normal distribution which should produce a nearly straight line. Figure 15 shows the JMP® output for the Q-Q plot and the residuals are within the margins of normality.



Quantiles

100.0%	maximum	195.7
99.5%		195.7
97.5%		171.5
90.0%		76.0
75.0%	quartile	39.3
50.0%	median	-3.7
25.0%	quartile	-44.6
10.0%		-79.2
2.5%		-134.0
0.5%		-174.9
0.0%	minimum	-174.9

Figure 15. Q-Q Plot

Figure 16 shows the output for the Shapiro-Wilk test, which tests the data to see if it is normally distributed. This test used a .05 alpha. Even though the p-value of this test was below .05, at a very close .0498, and suggests that the null hypothesis (snow removal operations degrade pavement markings) be rejected, researchers in this pilot study decided because the sample was so small (n=120) that the null hypothesis should not be rejected. This is validated by visually inspecting the distribution to determine that the data are from a normal population.

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.753e-14	-12.68745	12.687454
Dispersion	σ	70.190448	62.293345	80.398665

-2log(Likelihood) = 1359.83618237617

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.978329	0.0498*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure 16. Shapiro-Wilk Test

4.5 Noteworthy Field Lessons

Other preliminary assumptions are in reference to edgelines located near private mailboxes installed at the road's edges; the assumption is these data collection points will have less degradation because the plow trucks reduce the speed considerably (10-15 miles slower) to avoid projecting the snow and knocking over the mailboxes. Driving at reduced speeds is not annotated in any official procedural guidance but was observed during a 28 December 2009 ride-along during snow removal operations. The plow operator relayed that this was a common practice followed by all drivers to eliminate additional time and costs for the City of Beavercreek to replace the mailboxes.

The 10 thermoplastic marking data collection points were measured, recorded, plowed, and monitored in the same fashion as the 39 yellow centerline and 39 white edgeline data collection points. The same assumption is made regarding the brine

solution causing erratic retroreflectometer readings. There are no known or observed reasons for plow operators to reduce speed at the thermoplastic test sites as these spots were not located near private mailboxes.

Chapter 5: Conclusion

This research looked at white thermoplastic pavement markings located in the center of the roadway and how snow removal operations may cause these marking to degrade more rapidly. All marking were located in the center of the driving lane and thereby exposed to the maximum traffic and snow removal operations on the road. Based on literature reviewed, it seems that this research was unique in that the final model used included snow removal as an independent continuous variable. Pinpointing pavement marking lifecycles will assist all managers of this asset by allowing prudent allocation of funds used to maintain markings; this maintenance simply means marking reapplication when the end of their service lives are reached. Much of the previous research had to intuitively choose a R_L value that defined the end of service life. This thesis has an advantage over all previous research in that there are now proposed minimum R_L values; these values are to be included in the first revision of the 2009 MUTCD. These proposed values seem to have increased the speculated service life when implementing previously documented degradation rates.

5.1 Results

The thermoplastic markings on Beaver Valley Road were applied in October 2009; the data collection began December 2009 and terminated October 2010; therefore, 10 months of data has been collected and analyzed from Beaver Valley Road. Using the regression model and the examination of the outcomes of how the Beaver Valley Road data did not display a negative regression line was at first a bit disheartening. However, after some thought, a solid assumption is that the break-in phase of thermoplastic pavement markings that are exposed to snow removal operations occurs more than 12

months after initial application. This validates finding from the South Carolina study where the authors suggests "pavement marking retroreflectivity degrades linearly after a significant period after the marking is initially placed (in most cases, a year or more)" (Sarasua, et al. 2003).

5.2 Research Limitations

Since AFIT's graduate program runs 18-months, the main limitation of this pilot study was time. If the research could have continued throughout a second winter season and data were collected on the same 10 locations; it is very likely the crest of the break-in phase could have been observed and recorded. Perhaps the Vermont findings would have been validated, that marking degrades 100 mcd/m2/lx of R_L directly after a snow season (Fitch, 2007).

A second, although, minimal limitation is that the initial R_L value was obtained approximately 60 days after initial marking application. Ideally, the initial reading would be recorded 30 days after initial marking application, but in the TRB Synthesis, all initial readings were collected at 60 day. However, in the Beaver Valley Road reading the 60 days after application fell during the first half of the month of December, the average temperature was such that Beaver Valley Road had received; five applications of brine solution and one salt/limestone grit application to prevent freezing road conditions between 24 November 2009 and 10 December 2009. It is an assumption this brine solution and the salt/limestone grit application may have caused the initial R_L values recorded to be exceptionally low. Moreover, the solution and melting snow and ice on

the road could have played into the condensation factor as addressed in the HITECH study of retroreflectometers (HITEC, 2000).

5.3 Importance of Findings

With certainty thermoplastic pavement markings do not begin to their retroreflective decline for at least the first 12 months after initial application. This is important for asset managers so funds or other resources under their purview, are not allocated to collect marking R_L data (aside from the initial R_L value).

Considering the 1999 Michigan study, which stated that thermoplastic degrades at .14 percent a day, one could infer that Beaver Valley Road would degrade to the minimum level of 50 mcd/m^2/lx no sooner than 81 months once the apex of the break-in phase is reached (this assumes a 400 mcd/m2/lx initial R_L) (Lee, et al. 1999).

This means white thermoplastic markings, located in the middle of a road with an average daily traffic count of approximately 4000 vehicles; in regions that receive 27 inches of snow (or less) annually and conduct snow removal operations; should not even be considered for replacement until 7-1/2 years after initial application.

This can be a savings for any organization responsible for reapplication of thermoplastic markings.

5.4 Future Research

Further research is needed to determine exactly when the natural degradation will begin to occur. A great place to find perhaps pinpoint that timeframe is to continue to monitor the ten Beaver Valley Road locations.

Based on some previous studies, such as the 1994 Bagot Airfield Marking Study, it is clear that marking materials with same size beads degrade more rapidly when exposed to snow removal operations. So another venue to consider is monitoring markings in the same region, exposed to same ADT and snow removal operations, but that have different bead sizes.

The regions in the Michigan study received more annual average snow fall than Beavercreek Ohio. The Michigan study snow fall ranged from 40 to 100+ inches; whereas Beavercreek Ohio receives an annual average snowfall of 27.3 inches. Perhaps a great future research opportunity would be to match all things, except the amount of snow the markings are exposed to (which would increase the snow plow operations).

Bibliography

ASTM. (2009, February). ASTM E1710, Standard Test Method of Measurement of Retroreflective Pavement Markings with CEN-Prescribed Geometry Using a Portable Retroreflectometer.

Bagot, K. (1994). *Evaluation of Retro-Reflective Beads in Airport Pavement Markings.*

Biteman, M. (2009, December). (M. Monfette, Interviewer)

Brown, G. (2009, October 13). 2009/2010 Snow and Ice Removal Strategy. *Memorandum* . Beavercreek, Ohio: Superintendent of Public Service.

Carlson, P. (2009). Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. *Transportation Research Record: A Journal of the Transportation Research Board* , 59-68.

Craig, N., Sitzabee, W., Rasdorf, W., & Hummer, J. (2007). Statistical Validation of the Effect of Lateral Line Location on Pavement Marking Retroreflectivity Degradation. *Pulbic Works Management and Policy* , 431-450.

Create a Route. (2010). Retrieved February 2010, from USA Track and Field: http://www.usatf.org/routes/map/

Davis, R. (n.d.). *Materials Management.* Retrieved November 2010, from Ohio Department of Transportation: http://www.dot.state.oh.us/Divisions/ConstructionMgt/Materials/Pages/PAVEMENT-MARKING.aspx

Debaillon, C., Carlson, P., He, Y., Schnell, T., & Aktan, F. (2007). *Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs.* McLean: U.S. Department of Transportation.

Delta. (2004). *Reflection and retroreflection.* Retrieved September 2010, from http://www.madebydelta.com/imported/images/documents/Roadsensors/RS101.pdf

FHWA. (2009). *Manual for Uniform Traffic Control Devices.* Federal Highway Administration.

Fitch, J. (2007). *Pavement Marking Durability Statewide.* Agency of Transportation Materials and Research Section.

Flint Trading Inc. (n.d.). *Documents.* Retrieved November 2010, from Flint Trading Inc.: http://flinttrading.com/getdoc/07b03de8-9a2e-45f1-87d8-55ada4072c60/Specification_PreMark-SA-06-23-10.aspx

Gibson, J., Scherer, W., & Gibson, W. (2007). *How to Do Systems Analysis.* Wiley-Interscience.

Hatzi, P. (2001). *Retroreflectivity, Right Back at You.* Retrieved 2010, from Highway Technet: http://www.library.unt.edu/gpo/OTA/featproj/fp_te29.html

Hawkins, G. (2010, February). (M. L. Monfette, Interviewer)

Hawkins, G., Lupes, M., Schertz, G., Satterfield, C. S., & Carlson, P. (2010). *Revised Assessment of Economic Impacts of Implementing Minimum Levels of Pavement Marking Retroreflectivity.* Office of Safety. Federal Highway Administration.

Hawkins, H. G. (2000). *Evolution of the U.S. Pavement Marking System.* Texas Transportation Institute.

HITEC. (2000). *Evaluation Findings of the LTL 2000 Pavement marking Retroreflectometer.* Civil Engineering Research Foundation.

Lee, J.-T., Maleck, T., & Taylor, W. (1999). Pavement Marking Material Evaluation Study in Michigan. *Institute of Transportation Engineers* .

Migletz, J., & Graham, J. (2001). *NCHRP Synthesis 306-Long-Term Pavement Marking Pratices.* Transportation Research Board.

Random Number Generator. (n.d.). Retrieved September 2009, from Stat Trek: http://stattrek.com/Tables/Random.aspx

Rao, P. (1998). *Statistical Research Methods in the Life Sciences.* Brooks/Cole Publishing Company.

Sarasua, W., Clarke, D., & Davis, W. (2003). *Evaluation of Interstate Pavement Marking Retroreflectivity.*

Sasidharan, L., Karwa, V., & Donnell, E. T. (2009). Use of Pavement Marking Degradation Models to Develop a Pavement Marking Management System. *Public Works Management & Policy* . SAGE Publications.

Sitzabee. (2010, Fall/Winter Quarter). Class Lecture. Wright-Patterson AFB, Ohio.

Sitzabee, W. E., Hummer, J. E., & Rasdorf, W. (2009). Pavement Marking Degradation Modeling and Analysis. *Journal of Infrastructure Systems , 15*.

Suber, D. (2010, February). (M. Monfette, Interviewer)

Transportation, U. D. (2007). *Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs.* Federal Highway Administration.

U.S. Department of Transportation. (1999, December). Retrieved January 2011

U.S. Department of Transportation; Federal Highway Administration. (1999, December). *Asset Primer Manager*. Retrieved February 2010, from Federal Highway Administration: http://www.fhwa.dot.gov/infrastructure/asstmgmt/amprimer.pdf

Zwahlen, H., & T., S. (1998). *Pavement marking Visibility Research and Proposed Values for Minimum Required Pavement marking Retro Reflectivity*. Department of Industrial and Systems Engineering, Ohio University, Athens.

Appendix A: Data

Date/Day	Test Location	GPS North	GPS West	Average of 3 Readings
12 Dec 2009	1 = “L”	39 °43.770	- 084 °01.176	113
(day 0)	2 = “turn arrow”	39 °43.777	- 084 °01.175	143
	3 = “L”	39 °43.750	- 084 °01.179	191
	4 = “turn arrow”	39 °43.743	- 084 °01.178	144
	5 = “L”	39 °43.560	- 084 °01.238	365
	6 = “turn arrow”	39 °43.555	- 084 °01.238	214
	7 = “L”	39 °43.561	- 084 °01.238	162
	8 = “turn arrow”	39 °43.556	- 084 °01.240	186
	9 = “L”	39 °43.313	- 084 °01.319	88
	10 = “turn arrow”	39 °43.306	- 084 °01.324	151
18 Dec 2009	1 = “L”	39 °43.770	- 084 °01.176	165
(day 6)	2 = “turn arrow”	39 °43.777	- 084 °01.175	122
	3 = “L”	39 °43.750	- 084 °01.179	201
	4 = “turn arrow”	39 °43.743	- 084 °01.178	139
	5 = “L”	39 °43.560	- 084 °01.238	228
	6 = “turn arrow”	39 °43.555	- 084 °01.238	235
	7 = “L”	39 °43.561	- 084 °01.238	304
	8 = “turn arrow”	39 °43.556	- 084 °01.240	263
	9 = “L”	39 °43.313	- 084 °01.319	102
	10 = “turn arrow”	39 °43.306	- 084 °01.324	186
30 Dec 2009	1 = “L”	39 °43.770	- 084 °01.176	193
(day 18)	2 = “turn arrow”	39 °43.777	- 084 °01.175	129
	3 = “L”	39 °43.750	- 084 °01.179	210
	4 = “turn arrow”	39 °43.743	- 084 °01.178	143
	5 = “L”	39 °43.560	- 084 °01.238	228
	6 = “turn arrow”	39 °43.555	- 084 °01.238	190
	7 = “L”	39 °43.561	- 084 °01.238	321
	8 = “turn arrow”	39 °43.556	- 084 °01.240	251
	9 = “L”	39 °43.313	- 084 °01.319	122
	10 = “turn arrow”	39 °43.306	- 084 °01.324	195

18 Jan 2010	1 = “L”	39 °43.770	- 084 °01.176	115
(day 37)	2 = “turn arrow”	39 °43.777	- 084 °01.175	86
	3 = “L”	39 °43.750	- 084 °01.179	122
	4 = “turn arrow”	39 °43.743	- 084 °01.178	142
	5 = “L”	39 °43.560	- 084 °01.238	252
	6 = “turn arrow”	39 °43.555	- 084 °01.238	161
	7 = “L”	39 °43.561	- 084 °01.238	164
	8 = “turn arrow”	39 °43.556	- 084 °01.240	180
	9 = “L”	39 °43.313	- 084 °01.319	77
	10 = “turn arrow”	39 °43.306	- 084 °01.324	109
23 Jan 2010	1 = “L”	39 °43.770	- 084 °01.176	69
(day 42)	2 = “turn arrow”	39 °43.777	- 084 °01.175	59
	3 = “L”	39 °43.750	- 084 °01.179	88
	4 = “turn arrow”	39 °43.743	- 084 °01.178	93
	5 = “L”	39 °43.560	- 084 °01.238	160
	6 = “turn arrow”	39 °43.555	- 084 °01.238	176
	7 = “L”	39 °43.561	- 084 °01.238	251
	8 = “turn arrow”	39 °43.556	- 084 °01.240	215
	9 = “L”	39 °43.313	- 084 °01.319	54
	10 = “turn arrow”	39 °43.306	- 084 °01.324	141
5 Mar 2010	1 = “L”	39 °43.770	- 084 °01.176	232
(day 83)	2 = “turn arrow”	39 °43.777	- 084 °01.175	209
	3 = “L”	39 °43.750	- 084 °01.179	208
	4 = “turn arrow”	39 °43.743	- 084 °01.178	232
	5 = “L”	39 °43.560	- 084 °01.238	413
	6 = “turn arrow”	39 °43.555	- 084 °01.238	293
	7 = “L”	39 °43.561	- 084 °01.238	280
	8 = “turn arrow”	39 °43.556	- 084 °01.240	355
	9 = “L”	39 °43.313	- 084 °01.319	91
	10 = “turn arrow”	39 °43.306	- 084 °01.324	229

9 Apr 2010	1 = “L”	39 °43.770	- 084 °01.176	235
(day 118)	2 = “turn arrow”	39 °43.777	- 084 °01.175	190
	3 = “L”	39 °43.750	- 084 °01.179	152
	4 = “turn arrow”	39 °43.743	- 084 °01.178	202
	5 = “L”	39 °43.560	- 084 °01.238	444
	6 = “turn arrow”	39 °43.555	- 084 °01.238	385
	7 = “L”	39 °43.561	- 084 °01.238	435
	8 = “turn arrow”	39 °43.556	- 084 °01.240	233
	9 = “L”	39 °43.313	- 084 °01.319	124
	10 = “turn arrow”	39 °43.306	- 084 °01.324	232
10 May 2010	1 = “L”	39 °43.770	- 084 °01.176	251
(day 149)	2 = “turn arrow”	39 °43.777	- 084 °01.175	193
	3 = “L”	39 °43.750	- 084 °01.179	150
	4 = “turn arrow”	39 °43.743	- 084 °01.178	210
	5 = “L”	39 °43.560	- 084 °01.238	422
	6 = “turn arrow”	39 °43.555	- 084 °01.238	365
	7 = “L”	39 °43.561	- 084 °01.238	202
	8 = “turn arrow”	39 °43.556	- 084 °01.240	452
	9 = “L”	39 °43.313	- 084 °01.319	148
	10 = “turn arrow”	39 °43.306	- 084 °01.324	233
7 Jul 2010	1 = “L”	39 °43.770	- 084 °01.176	345
(day 207)	2 = “turn arrow”	39 °43.777	- 084 °01.175	264
	3 = “L”	39 °43.750	- 084 °01.179	307
	4 = “turn arrow”	39 °43.743	- 084 °01.178	296
	5 = “L”	39 °43.560	- 084 °01.238	514
	6 = “turn arrow”	39 °43.555	- 084 °01.238	373
	7 = “L”	39 °43.561	- 084 °01.238	469
	8 = “turn arrow”	39 °43.556	- 084 °01.240	244
	9 = “L”	39 °43.313	- 084 °01.319	177
	10 = “turn arrow”	39 °43.306	- 084 °01.324	326

5 Aug 2010	1 = “L”	39 °43.770	- 084 °01.176	386
(day 236)	2 = “turn arrow”	39 °43.777	- 084 °01.175	309
	3 = “L”	39 °43.750	- 084 °01.179	331
	4 = “turn arrow”	39 °43.743	- 084 °01.178	345
	5 = “L”	39 °43.560	- 084 °01.238	531
	6 = “turn arrow”	39 °43.555	- 084 °01.238	401
	7 = “L”	39 °43.561	- 084 °01.238	518
	8 = “turn arrow”	39 °43.556	- 084 °01.240	272
	9 = “L”	39 °43.313	- 084 °01.319	204
	10 = “turn arrow”	39 °43.306	- 084 °01.324	360
10 Sep 2010	1 = “L”	39 °43.770	- 084 °01.176	385
(day 272)	2 = “turn arrow”	39 °43.777	- 084 °01.175	309
	3 = “L”	39 °43.750	- 084 °01.179	341
	4 = “turn arrow”	39 °43.743	- 084 °01.178	320
	5 = “L”	39 °43.560	- 084 °01.238	484
	6 = “turn arrow”	39 °43.555	- 084 °01.238	375
	7 = “L”	39 °43.561	- 084 °01.238	405
	8 = “turn arrow”	39 °43.556	- 084 °01.240	238
	9 = “L”	39 °43.313	- 084 °01.319	217
	10 = “turn arrow”	39 °43.306	- 084 °01.324	339
12 Oct 2010	1 = “L”	39 °43.770	- 084 °01.176	414
(day 305)	2 = “turn arrow”	39 °43.777	- 084 °01.175	323
	3 = “L”	39 °43.750	- 084 °01.179	361
	4 = “turn arrow”	39 °43.743	- 084 °01.178	341
	5 = “L”	39 °43.560	- 084 °01.238	558
	6 = “turn arrow”	39 °43.555	- 084 °01.238	402
	7 = “L”	39 °43.561	- 084 °01.238	530
	8 = “turn arrow”	39 °43.556	- 084 °01.240	232
	9 = “L”	39 °43.313	- 084 °01.319	244
	10 = “turn arrow”	39 °43.306	- 084 °01.324	385

Appendix B: Beavercreek Snow Strategy

MEMORANDUM

To: Michael A. Cornell, City Manager

From: Gary Brown, Superintendent of Public Service

Re: 2009/2010 Snow and Ice Removal Strategy

Date: October, 13th 2009

Cc: David Beach, Director of Public Service

<u>2009/2010 Snow and Ice Removal Strategy</u>

1. **Predicted storm events**: Salt brine will be applied to all streets within the City of Beavercreek prior to storm events and as long as the dew point and the air temperature have a five degree spread or unless rain is forecast. The application of brine shall occur as follows: U.S. 35 and primary arterial streets within the city limits shall be treated first followed by residential collector streets and then remaining plat streets. This will be in advance of a predicted winter storm and may be applied up to several days in advance of an expected storm. This will apply also to expected bridge frost or the snow which can accumulate on bridges and hills. Primary bike paths located along Dayton-Xenia and Kemp Road will also be treated.

2. **Snow events that are in the range from 0-3 inches shall be treated as follows**: All streets & roadways with the exception of U.S. 35 shall receive a mixture of salt and limestone grit to be mixed at a 1 to 1 ratio. Straight salt shall be used on U.S. 35 because of the higher roadway speed to avoid grit accumulating at intersections and becoming a hazard when stopping suddenly. S.R. 835 will be evaluated before straight salt is utilized. Treatment priorities shall be applied in this order, primary arterials, residential collectors and lastly plat streets and cul-de-sacs.

3. **Snow events greater than 3 inches**: Shall be plowed in a manner that allows each lane on primary arterials to be plowed and treated with mixed materials (salt and grit) and then proceed into plat streets plowing one round on each street and the street being treated on the outbound return of the last pass. (i.e. plow only from beginning point to turn around point, then plow and apply salt & grit mixture on the return to the beginning point.) ONLY after the entire street system has been treated and plowed for traffic shall crews return to plow the balance of the street to the curb if so needed.

4. **Snow events greater than 6 inches:** Contractors will be contacted to assist in the clearing of cul-de-sacs. City crews will plow into cul-de-sacs, turn around and plow out as the large trucks cannot do plowing in cul-de-sacs given size of trucks. Smaller units such as backhoes and pickup trucks will also be assigned to clear cul-de-sacs and to assist in clearing blocked driveways when emergency requests are received. Crews will continue service until storm response is complete.

5. **Major Snow events:** Street crews will focus on arterial streets until such time as roadways become passable to traffic and then will proceed into plats addressing residential collector streets first, then the balance of local streets. Once the storm has exhausted itself or moved from the area, the plow procedure listed in Step 3 will be followed as outlined above.

<u>**Other Considerations**</u>

1. Decisions regarding the percentage of salt and grit use as outlined above may be dependent on wind conditions and post storm weather conditions. Events, such as ice storms, will be evaluated on a case by case basis.

2. Coordination efforts with the township and schools are being finalized at this time.

3. Additional contractors are being solicited as well for major snow events.

4. Live telephone response to citizen inquiries is currently being finalized with administrative staff for all after hour snow events.

Appendix C: JMP® Output

Stepwise Fit

Response:Current RL

Stepwise Regression Control

Prob to Enter 0.050
Prob to Leave 0.050

Direction: Mixed

Current Estimates

SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AICc
586277.17	117	5010.916	0.6461	0.6401	3	1368.18

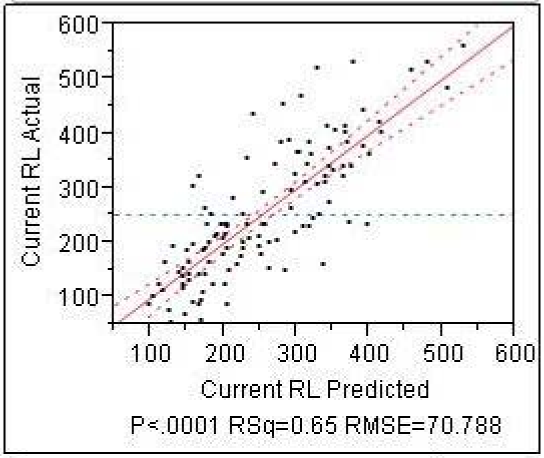
Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Intercept	30.7434718	1	0	0.000	1
		Age (days)	0.74086507	1	720407.7	143.768	4.3e-22
		RLI	0.74800043	1	350044.7	69.856	1.5e-13

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	Age (days)	Entered	0.0000	720407.7	0.4348	70.856	2
2	RLI	Entered	0.0000	350044.7	0.6461	3	3

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.646124
RSquare Adj	0.640075
Root Mean Square Error	70.78782
Mean of Response	253.1083
Observations (or Sum Wgts)	120

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1070452.4	535226	106.8120
Error	117	586277.2	5011	Prob > F
C. Total	119	1656729.6		<.0001*

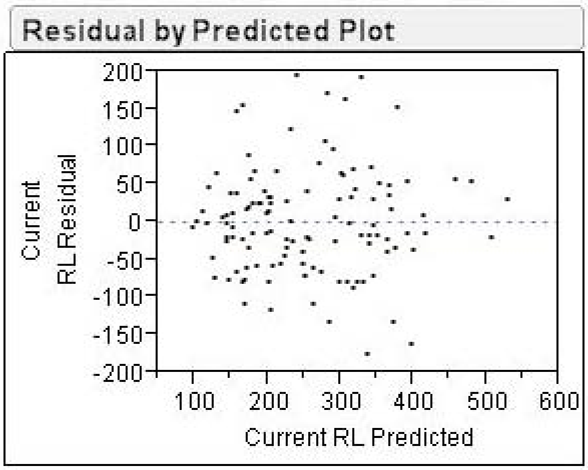
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	30.743472	18.61547	1.65	0.1013
RLI	0.7480004	0.089495	8.36	<.0001*
Age (days)	0.7408651	0.061789	11.99	<.0001*

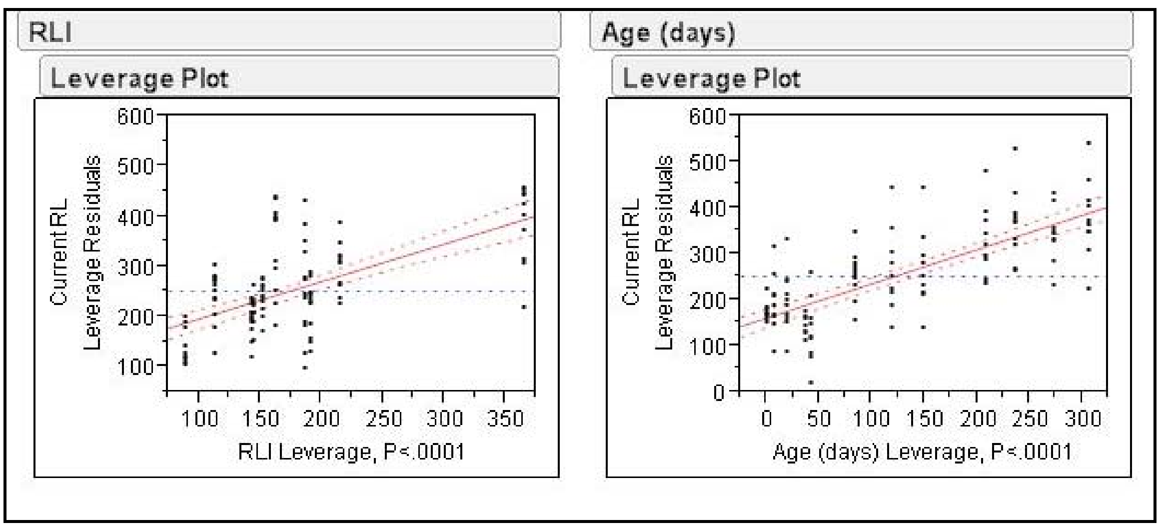
***The *Adjusted* R^2 is .646 and that is consistent with other predictive models in previous literature.

Prediction Expression

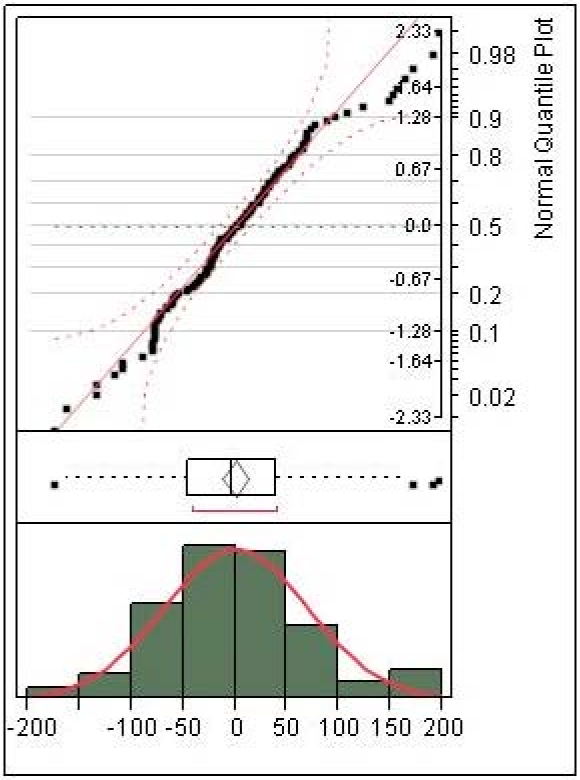
30.7434717876886
+0.7480004258086*RLI
+0.74086506501892*Age (days)



***The *Residual by Predicted Plot* shown to the left, depicts an even distribution of the residuals (no cone or fan shape), validating an normal population



Residual Current RL



Normal(1.8e-14,70.1904)

***The *Q-Q Plot* and the *Histogram* shown to the left, both represent normality.

The *Q-Q Plot* shows a line within the boundaries.

The *Histogram* is fitted with a bell curve that depicts a fairly symmetrical distribution from the mean for the sample population of 120, this validates the sample is representative of a normal population

Quantiles

100.0%	maximum	195.7
99.5%		195.7
97.5%		171.5
90.0%		76.0
75.0%	quartile	39.3
50.0%	median	-3.7
25.0%	quartile	-44.6
10.0%		-79.2
2.5%		-134.0
0.5%		-174.9
0.0%	minimum	-174.9

Moments

Mean	1.753e-14
Std Dev	70.190448
Std Err Mean	6.4074819
Upper 95% Mean	12.687454
Lower 95% Mean	-12.68745
N	120

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.753e-14	-12.68745	12.687454
Dispersion	σ	70.190448	62.293345	80.398665

-2log(Likelihood) = 1359.83618237617

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.978329	0.0498*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

*****The** *Shapiro-Wilk Test* shown above has a P-value less than .05 α, which suggest we should reject the null hypothesis. However, because the sample is small, 120, we can choose not to reject the null (validated by visual inspecting the distribution).

Appendix D: Safety Plan

18 December 2009

MEMORANDUM FOR LT COL WILLIAM E. SITZABEE

FROM: MSgt Monica Monfette

SUBJECT: Safety Plan for Collecting Pavement Marking Data

1. This memorandum outlines safety measures to be implemented during data collection activities. All safety measures are in accordance with *Manual on Uniform Traffic Control Devices* (MUTCD).

2. Data collection will occur on Beavervalley Road during non-peak daytime traffic hours. According to MUTCD Beavervalley Road is considered a low volume road and the duration of each data collection session will be less than 60 minutes. Therefore, the safety measures that will be implemented each time data are collected are as follows:

   a. Data will always be collected with a minimum of two personnel
   b. Set up of an orange sign warning vehicles of work ahead and/or lane closure
   c. Use of a strobe type beacon on work vehicle
   d. Safety vests worn by all individuals.

3. If you have any further questions please contact me at Comm 808-753-4776.

Monica Monfette

MONICA MONFETTE
MSgt, USAF

Will E. Sitzabee

WILLIAM E. SITZABEE, Ph.D., P.E.
Lt Col, USAF
Research Advisor, AFIT/ENV

JEREMY M. SLAGLEY, Ph.D.
Maj, USAF
Unit Safety Representative

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
24-MAR-2011	MASTER 'S THESIS	SEP 2009 – MAR 2011

4. TITLE AND SUBTITLE Impact of Snow Removal Operations on Thermoplastic Pavement Markings	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Monfette, Monica, L., MSgt, USAF	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765	**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GEM/ENV/11-M08
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Intentionally Left Blank	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UMNLIMITED

13. SUPPLEMENTARY NOTES
This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States

14. ABSTRACT
This pilot study explored the effect snow removal operations have on thermoplastic pavement markings. Including snow removal as a separate independent variable is unique because much of the previous research performed on pavement marking degradation mentioned snow removal as a direct cause in a marking degrading more rapidly; however, it is mentioned as an afterthought and a suggestion to be considered in future research. This pilot study looked at 10 thermoplastic markings and all marking data were collected in the field, using a hand-held retroreflectometer. Data collected began 60 days after initial marking application and ended 12 months after initial marking application. Data were analyzed using linear regression. A significant finding was that during the first year, white thermoplastic markings located in the center of the road, and that are exposed to snow removal operations do not reach the apex of their break-in phase. Thus the start of the linear degradation phase does not start until at least one year after initial application.

15. SUBJECT TERMS
Retroreflectivity, Thermoplastic, Pavement Markings, Snow Removal, Hand-held Retroreflectometer

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Lt Col William E. Sitzabee ENV
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	72	937-255-3636 ext. 7395

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

	Form Approved *OMB No. 074-0188*